Evaluation of Spark Gap Technologies for High Current, High Charge Transfer Switches

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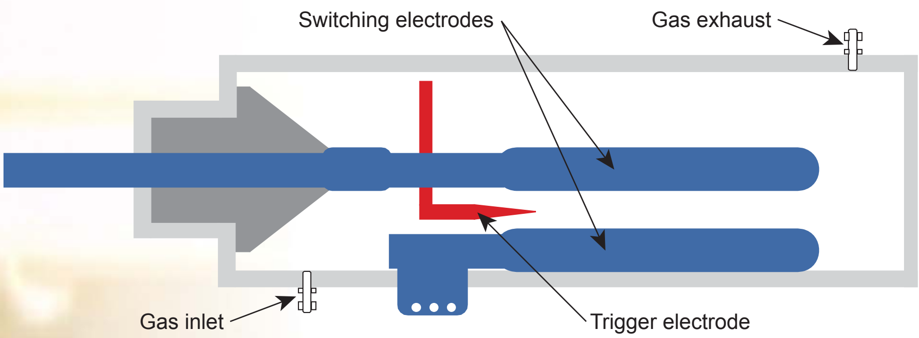
High energy pulsed power applications often require closing switches capable of handling hundreds of kiloamps of current and transferring hundreds of coulombs per shot. These systems, such as EM launchers and large laser amplifiers, have long relied on a rather limited variety of switching technologies capable of satisfying the necessary current and charge transfer requirements. Triggered spark gaps of varying types have largely remained the standard solution in pulsed power switching, but electrode erosion is a predictable problem due to the nature of the switch's operation.

Spark gaps produce a localized high temperature plasma as the conduction path between the electrodes, and exposure to this plasma inevitably leads to electrode erosion. Erosion can occur by several related mechanisms, but the effect of each is essentially the same. Material is lost from the electrode, degrading its original shape, and that material then gets deposited on the surfaces of insulators within the switch. Both phenomena can lead to decreased switching performance, unreliable triggering and decreased lifetime resulting in added cost for maintenance and replacement.

Figure 1. Basic geometry and features of a linear moving arc gap.



It is possible to mitigate the effects of electrode erosion and extend the effective lifetime of a switch, but the ideal solution would minimize or eliminate the issue altogether. There are switch geometries in production that use the Lorentz force to move the arc along an electrode in order to distribute the energy over a larger area, reducing the localized effects of single point arcing as seen in a standard spark gap.

Project Goals

The goal of this project was to conduct a trade study and literature search to evaluate commercially available switching technologies with a focus on moving arc switches and potential improvements to existing switches that would result in higher reliability and lower overall cost. Innovative solutions in the form of switch geometries and electrode materials were a particular focus. Future goals would include testing a specific switch on an in-house test stand and applying those results to improved switches for pulsed power and power conditioning systems.

Relevance to LLNL Mission

A robust, high-energy switch with lower total cost would be a highly useful addition to the pool of technologies currently used at LLNL in pulsed power and power conditioning applications. The project emphasis is on highlighting switch technologies that have the potential to achieve higher reliability and lower operating costs as compared to a traditional spark gap. Numerous efforts in National Security, Defense Technologies, Laser Systems, and Energy Manipulation that involve pulsed power and power conditioning systems will benefit from a lower cost, low maintenance, and highly reliable switch.

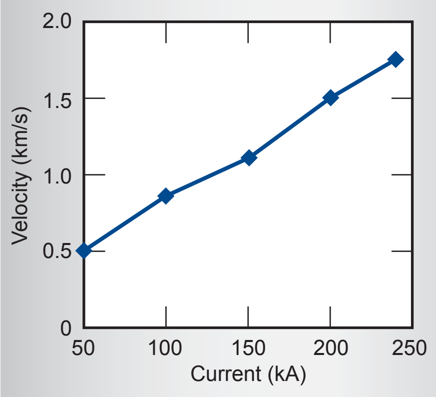


Figure 2. Projected average arc velocity vs. peak current for linear arc gap.

FY2008 Accomplishments and Results

In examining the currently available approaches to high-energy switching, the most promise was seen in moving arc switches. A linear moving arc gap switch (Figs. 1 to 3) was selected for the LMJ (Laser Mégajoule Project, a French effort similar to NIF) to satisfy their high charge transfer requirements, and it has demonstrated excellent reliability and a lifetime in excess of 22,000 shots without maintenance. Similarly, rotary arc gaps have also been used reliably in high energy switching applications, but commercially available units tend to have very high triggering requirements and necessitate a high-pressure gas system.

The geometry of the moving arc switch can be adapted to almost any switching requirements. Based on voltage hold-off, charge transfer requirements, and peak current, a moving arc switch could be tailored to any application provided the required linear length did not make it impractical. Should the linear length be constrained, a rotary arc gap would be a possible alternative.

In examining experimental results for various electrode materials, we found that copper was the best choice for nearly all applications. Other materials such as tungsten, tantalum, graphite, and hybrid material matrixes were the focus of several experiments, and in the vast majority of cases they did not offer substantial gains in electrode longevity when compared to copper. In addition, these materials were found to be more expensive and harder to work with than copper.

Related References

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FY2009 Proposed Work

Given the results of the literature search and the current state of the art, future work would focus on increasing in-house expertise on linear arc gap implementation. This would ideally be achieved through on-site experimentation on a test stand, which would also provide experimental data for electromagnetic and electromechanical computer code validation.

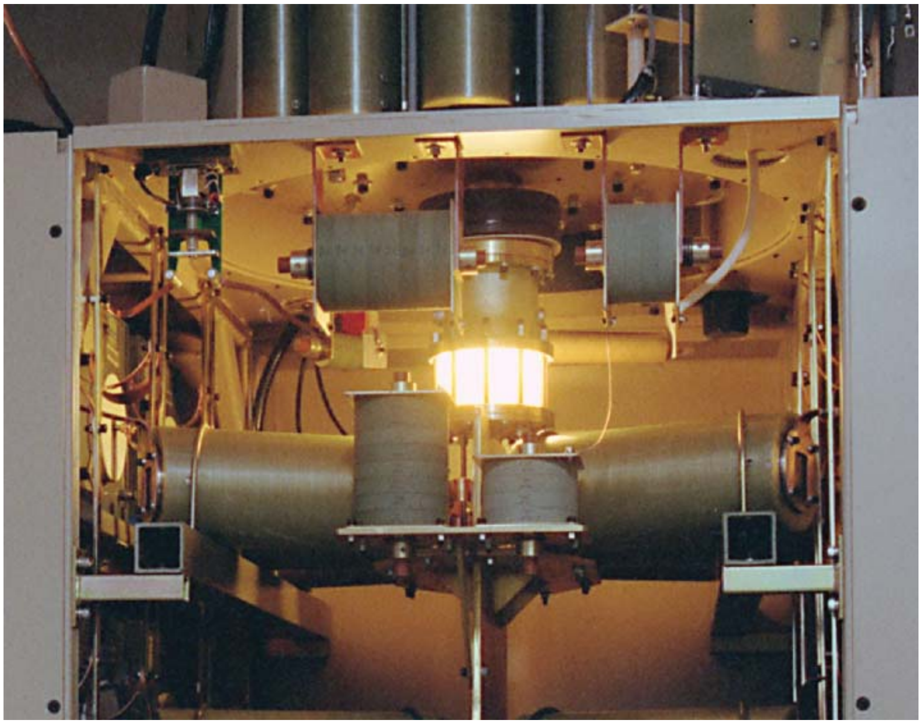

Figure 3. 500-kA Spark gap switch being discharged in one of the NIF power conditioning modules. There are 192 such modules in NIF. This high-current switch will require refurbishment approximately every 1,500 to 2,000 shots over an estimated NIF lifetime of 20,000 shots.